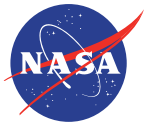

Jet Propulsion Laboratory
California Institute of Technology

Telemetry Ranging Recommendation Update

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November 7, 2017

This research was carried out by the Jet Propulsion Laboratory, California Institute of Technology, under a contract with the National Aeronautics and Space Administration.

Action Items (1/2)

- AI_16-05: Update the proposed telemetry ranging recommendation based on the received comments

  Status: Closed at Spring 2017 meeting.

- AI_16_06: Analyze the telemetry ranging scheme alternative without PN ranging in the uplink

  Status: Open.

- AI_17-02: Verify performance of TLM ranging with punctured code

  Status: Open.

Action Items (2/2)

- (In minutes, but un-numbered): Align recommendation more closely with GMSK+PN RNG ones (4.22A/B) including
  - specifying targeted frequencies and missions,
    Status: Done.
  - removing subconsiderings,
    Status: This is not understood. Subconsiderings are where the justifications are for the approach.
  - making recommend (1) less biased,
    Status: Done. Removed reference to “advantages” in considerings.
  - following 401 conventions for references,
    Status: Done. Footnotes and in-line references now used.
  - adding performances (ranging accuracy, telemetry throughput loss, etc.) in considerings,
    Status: Done. Considerings (h) and (i) added.
  - listing constraints in recommends (e.g., if data rate must be above certain amount),
    Status: Done.
  - aligning the equations with the GMSK+PN GB.
    Status: Done. Notation has been followed from 413.1-G-1.

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Backup

References for Telemetry Ranging

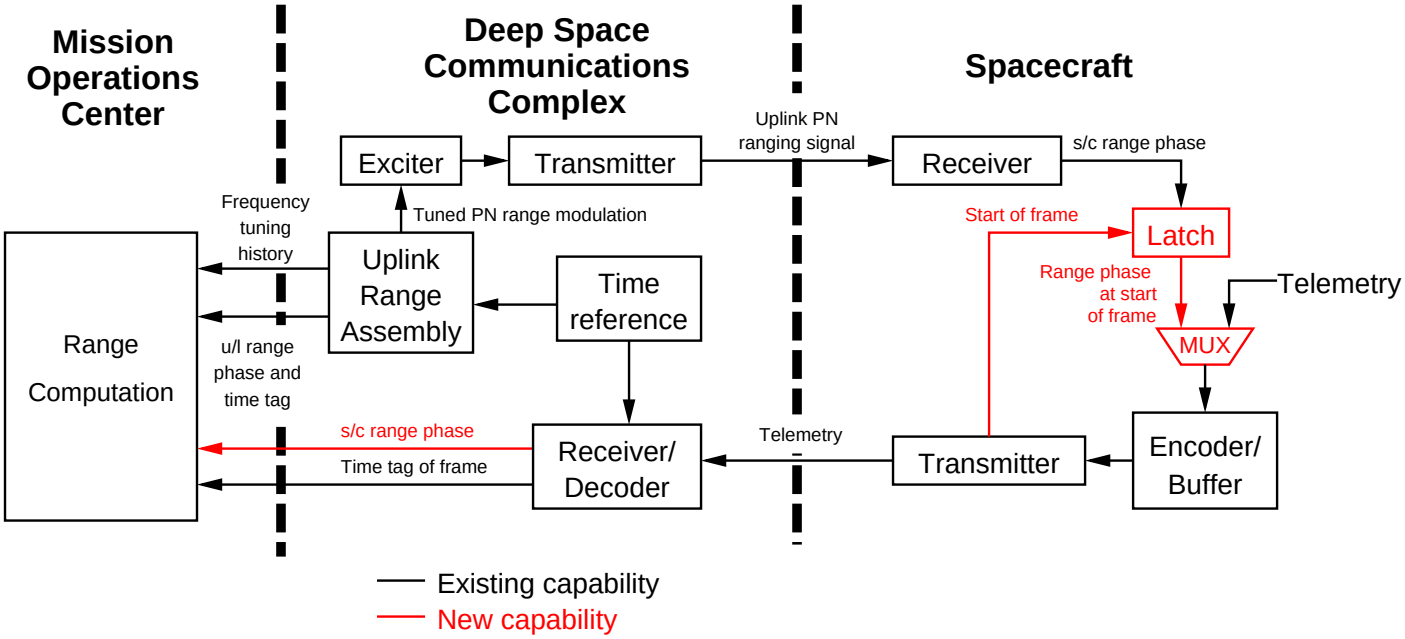
1. J. Hamkins, P. Kinman, H. Xie, V. Vilnrotter, and S. Dolinar, “Telemetry ranging: Concepts,” The Interplanetary Network Progress Report, vol. 42-203, Jet Propulsion Laboratory, Pasadena, California, pp. 1-21, November 15, 2015.
   http://ipnpr.jpl.nasa.gov/progress report/42-203/203C.pdf

2. J. Hamkins, P. Kinman, H. Xie, V. Vilnrotter, and S. Dolinar, “Telemetry ranging: Signal Processing,” The Interplanetary Network Progress Report, vol. 42-204, Jet Propulsion Laboratory, Pasadena, California, pp. 1-56, February 15, 2016.
   http://ipnpr.jpl.nasa.gov/progress_report/42-204/204D.pdf

3. J. Hamkins, P. Kinman, H. Xie, V. Vilnrotter, S. Dolinar, N. Adams, E. Sanchez, and W. Millard, “Telemetry Ranging: Laboratory Validation Tests and End-to-End Performance,” The Interplanetary Network Progress Report, vol. 42-206, Jet Propulsion Laboratory, Pasadena, California, pp. 1-35, August 15, 2016.
   http://ipnpr.jpl.nasa.gov/progress_report/42-206/206D.pdf

Overview of Telemetry Ranging

Top Level Implementation:



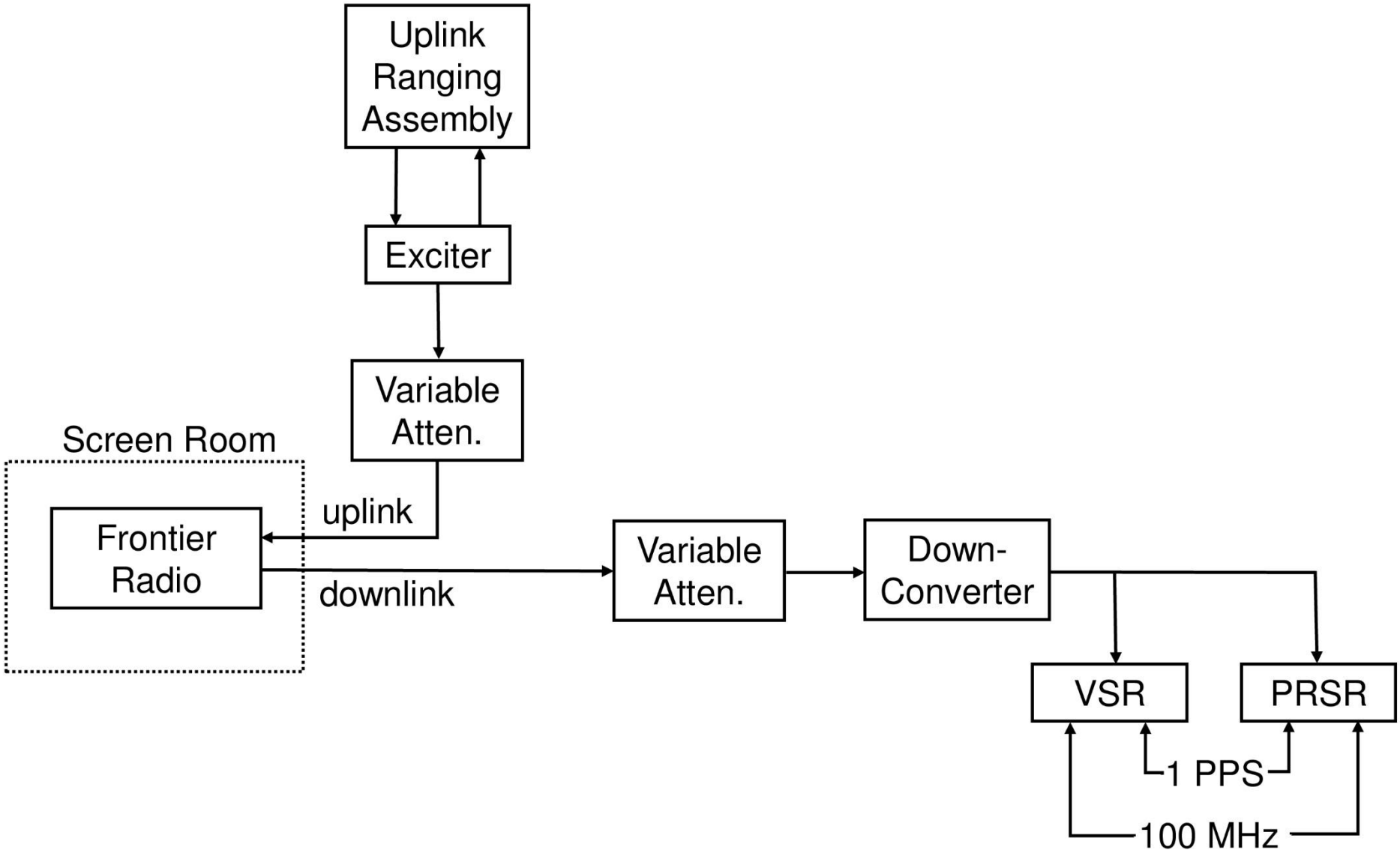
Data flow and range computation

1. PN ranging signal is sent on uplink; as it is transmitted, its phase is periodically recorded and time-tagged on ground (as usual with 2-way PN ranging).
2. Spacecraft records phase of acquired uplink PN signal *at moment when telemetry frame is transmitted. There is no downlink PN range signal.*
3. Range is computed from known uplink frequency tuning history, time-tagged PN phase from uplink range assembly, PN phase recorded on spacecraft, and time tag of telemetry frame. The range computation algorithm remains nearly unchanged.

Laboratory Validation

- A set of tests of telemetry ranging were conducted at DTF-21, using the Frontier Radio from JHU/APL.
- The Frontier Radio was set to lock on the uplink range code, latch the range code phase at appropriate intervals, insert these values into downlink telemetry frames, and transmit turbo-encoded telemetry on the downlink.
- Open-loop recorders recorded the downconverted telemetry signals.
- Post-processing attempted to receive, decode, and extract the spacecraft phase measurements.

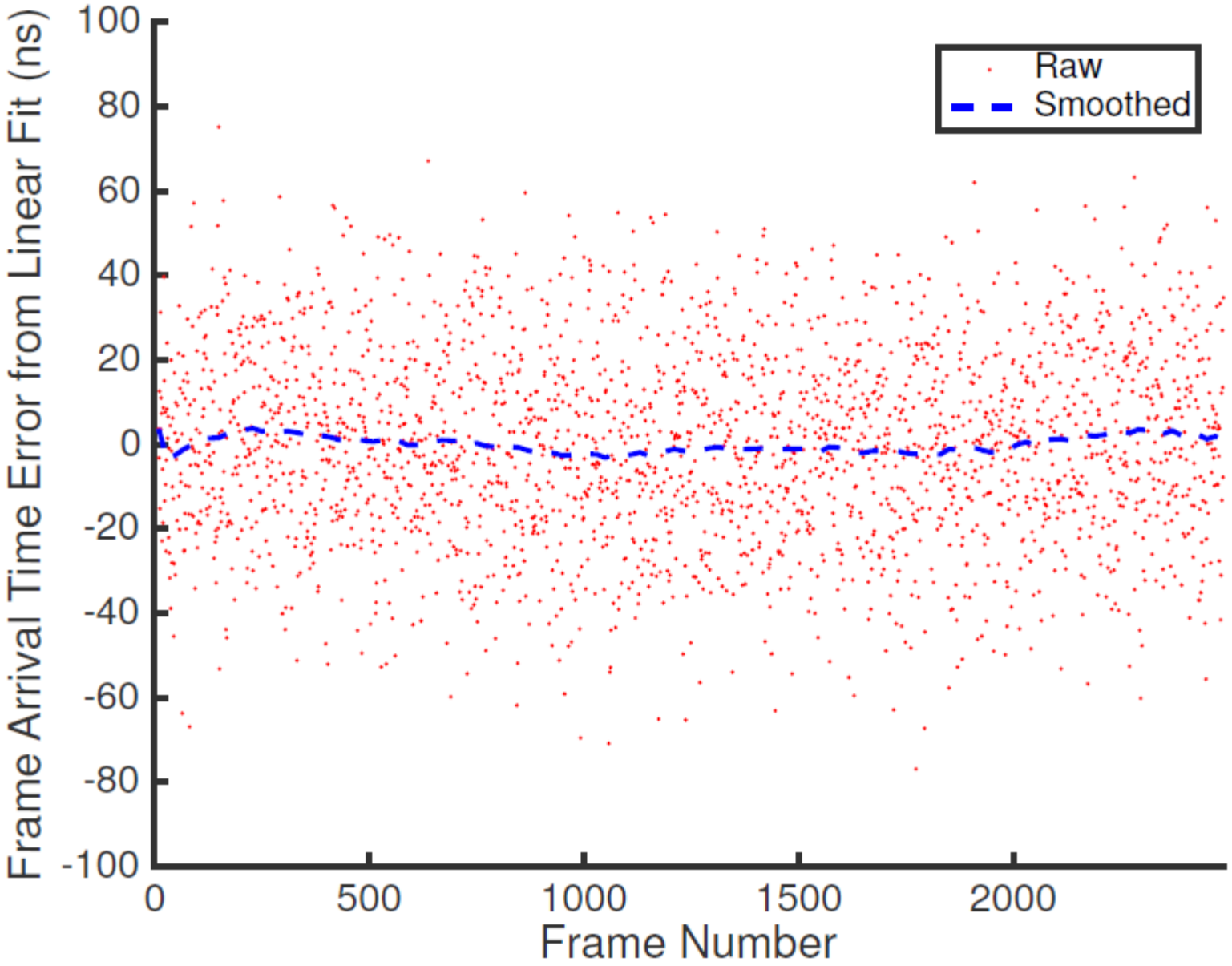
Laboratory Validation – Experimental Set-Up



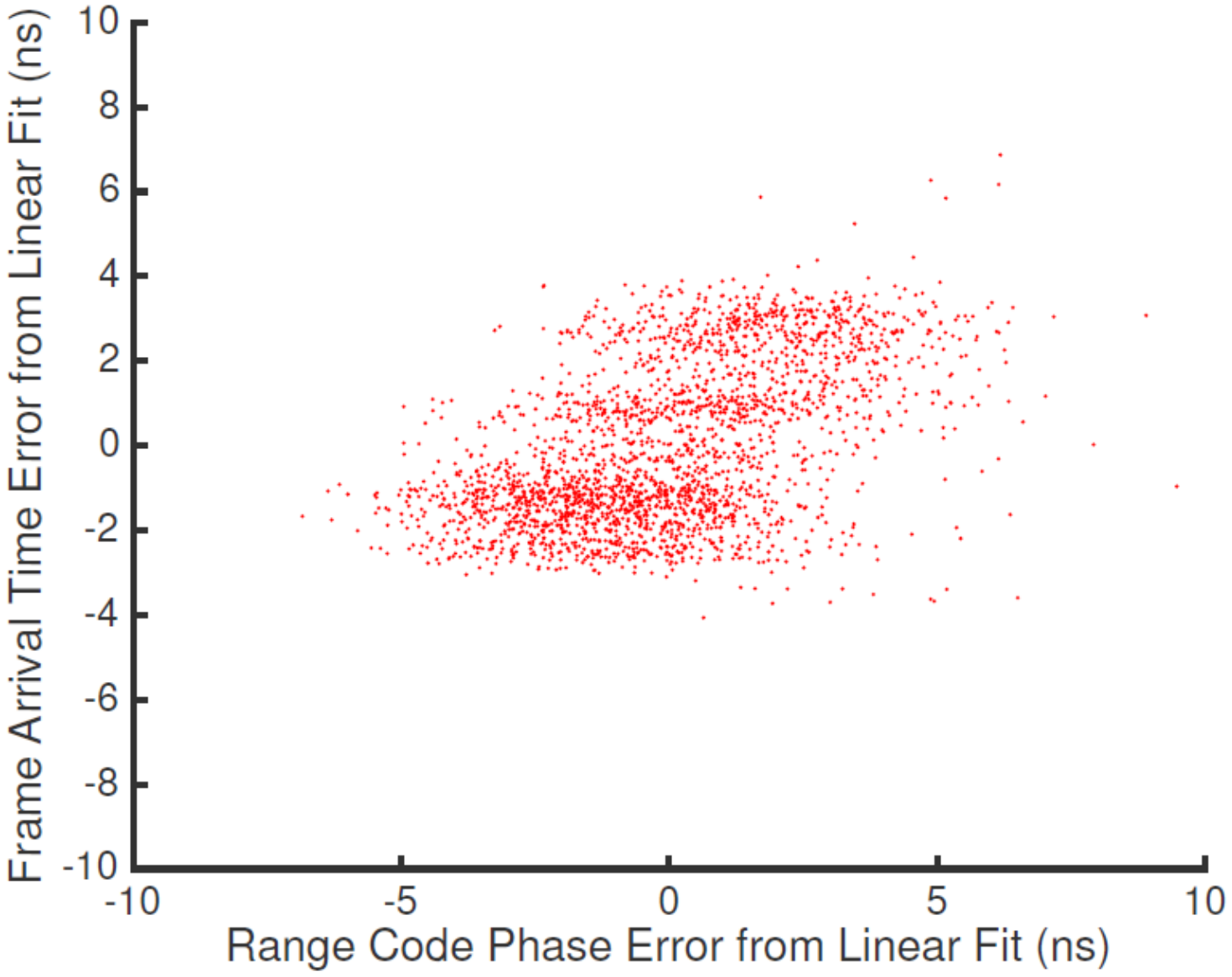
Laboratory Validation – Test Parameters

	Parameter	Value(s)
Uplink		
	Carrier frequency (f_c)	7176.182859 MHz
	PN ranging type	DSN standard [6]
	Range clock frequency	$(221/(749 \cdot 2048)) \times f_c = 1.0338892$ MHz
	Range mod. index	0.7 rad
Downlink		
	Carrier frequency	$(880/749) f_c = 8431.296295$ MHz
	Mod. index	1.21 rad
	Channel code	(a) CCSDS (1784, 1/6) turbo code, (b) no coding
	Randomization	(a) On, (b) off
	Ranging	(a) Present on downlink, (b) not present
	Symbol rate	(a) 90.09014 ksps, (b) 600 ksps
	SNR	Variable

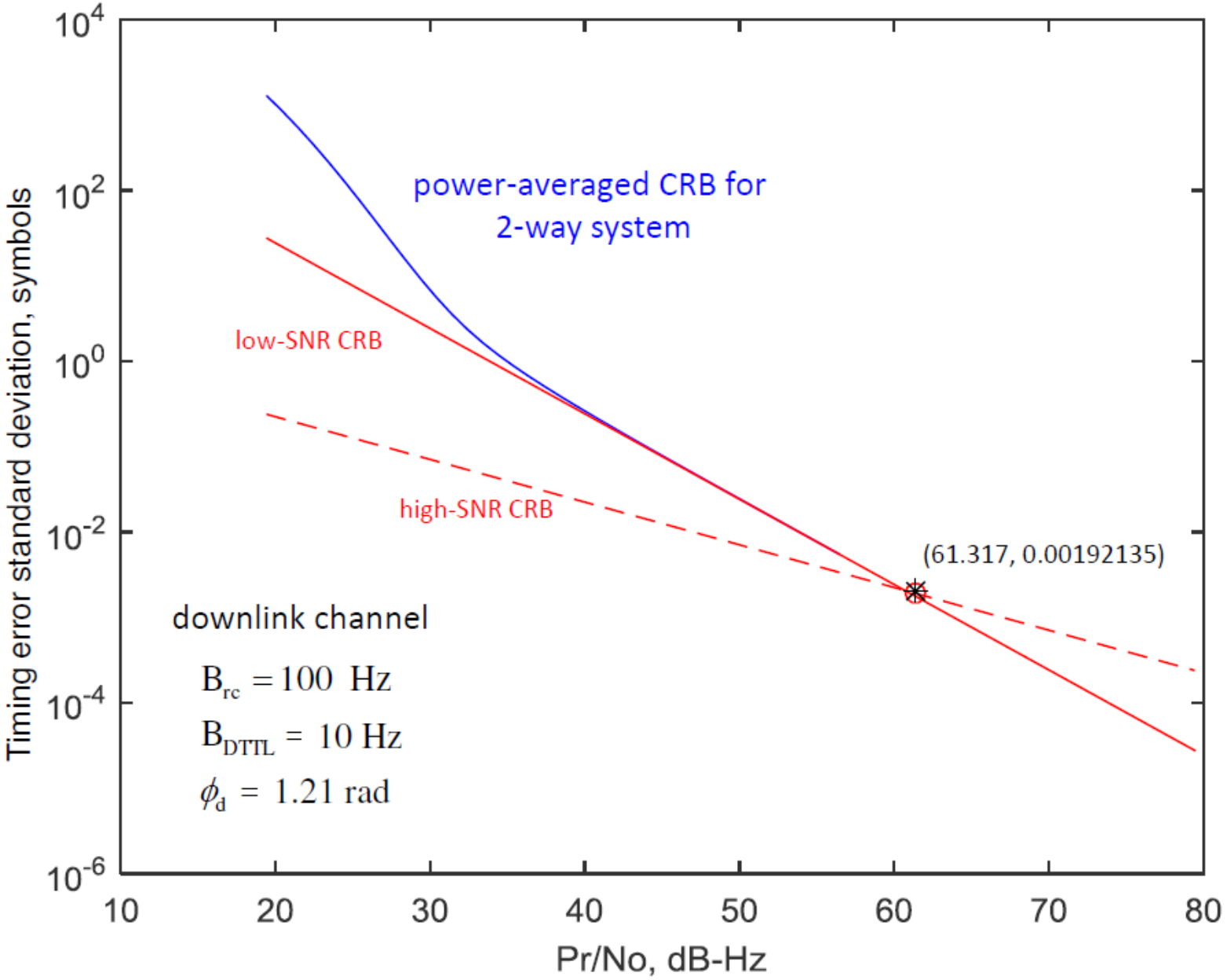
Downlink Frame Arrival Time Error



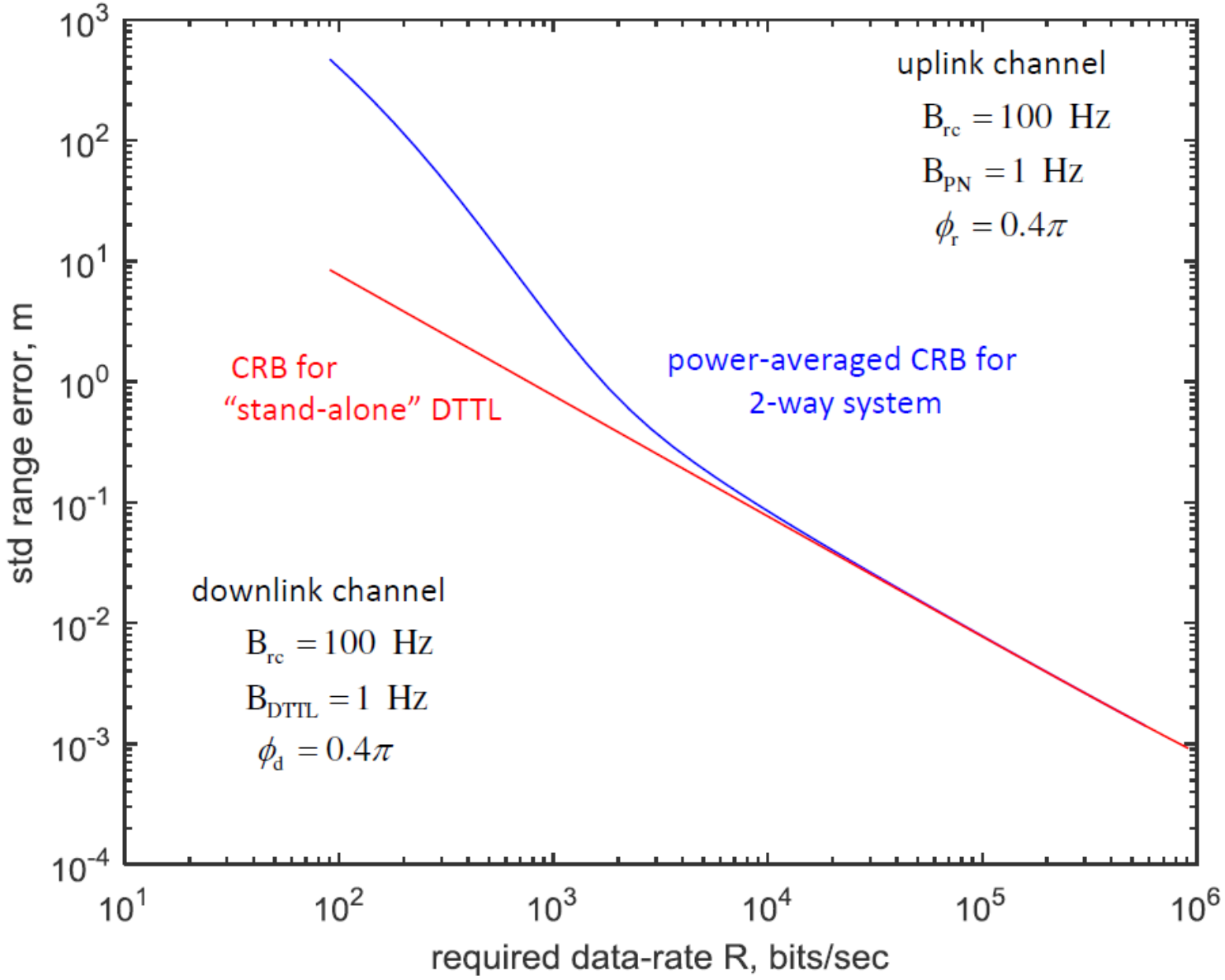
Measured Timing Error on Uplink and Downlink



Theory vs. Laboratory Measurement



Ranging Accuracy as Function of Data Rate



Conclusions

- A set of tests of telemetry ranging were conducted at DTF-21, using the Frontier Radio from JHU/APL.
- When the laboratory set-up was properly configured, post-processing of recorded data was able to identify time of arrival of the telemetry frames, to within 2.1 to 3.4 ns.
- End-to-end performance analysis is consistent with the observed variance of the end-to-end laboratory tests.

- For certain scenarios considered (rate-1/6 turbo code operating at threshold), the telemetry ranging approach is capable of resolving range to less than a meter when the data rate is more than 1 kbps.

- This suggests that telemetry ranging may be feasible and sufficiently accurate for typical deep space missions.